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Energy and water tradeoffs in enhancing food security: A Selective International Assessment

Shahbaz Mushtaq[a,1], Tek Narayan Maraseni[a], Jerry Maroulis[a], Mohsin Hafeez[b],

[a]*Australian Centre for Sustainable Catchments, University of Southern Queensland, Toowoomba, Qld 4350, Australia*
[b]*International Centre of Water for Food Security, Charles Sturt University, Wagga Wagga, NSW 2678, Australia*

Abstract

Rice is the major staple food in most Asian countries. However, with rapidly growing populations, sustained high productivity and yields through improving water productivity is critically important. Increasingly complex energy-agriculture relationships require an in-depth understanding of water and energy tradeoffs. This study contributes to energy and food policies by analysing the complex energy, water and economics dynamics across a selection of major rice growing countries.

The results show that tradeoffs exist between yield and energy inputs with high yield attributed to higher levels of energy input. The selected developed countries show higher energy productivity, relative to all other energy inputs, compared to the selected developing counties, owing to enhanced mechanisation, on-farm technology and improved farm management. Among all countries, China has the highest water productivity due to water-saving irrigation practices. These practices offer opportunities for developed and developing countries to increase water productivity at the same time taking advantage of economic and energy benefits of

[1] Correspondence to: Shahbaz Mushtaq. E-mail: mushtaqs@usq.edu.au; Phone 61-7-463 2019; Fax 61-7-4631 5581

reduced pumping. While greater water productivity will almost certainly be necessary to reduce the negative impacts of future water scarcity, it is crucial to bear in mind the trade-off between energy and water productivity. Development of efficient water irrigation practices such as alternate wetting and drying irrigation practice and their large scale implementation across the countries will result in increased rice productivity, reduced energy dependency, natural resource sustainability and ensure long term food security.

Key words: Water productivity; energy efficiency; benefit cost analysis; developed and developing countries; canal irrigation systems; tubewell irrigation system; rainfed irrigation system

1. Introduction

Rice is not only a staple food on a global scale, but also constitutes the major economic activity and a key source of employment and income for rural populations. Some 75% of the world's annual rice production is harvested from 79 million ha of irrigated lowland rice, mainly in Asia where it accounts for 40-46% of the net irrigated area of all crops (Dawe, 2005). Since the Green Revolution of the 1960s, the combination of new high yielding rice varieties has resulted in the dramatic and sustained increase in rice production. This increased productivity and profitability also contributed to enhanced food security and less poverty among farmers with irrigated land (Dawe, 2000).

Rice is one of the largest users of the world's developed freshwater resources (Tuong and Bouman, 2003). Bouman et al. (2007) estimated that 34-43% of the total world's irrigation water is used in rice production. However, increasing water scarcity, maintenance of aging irrigation systems, and increased competition for water from other sectors, and the low water productivity of rice relative to other cereal crops (Tuong et al. 2005) means that the sustainability of rice is under threat (Rijsberman, 2006). The strong interdependence between water use in rice production and the operation of irrigation facilities for water services highlights the need for improving the performance of rice production systems (Bhuyan, 1996) with Rijsberman (2006) advocating that water scarcity can be addressed through improved water productivity. Increasing water productivity not only requires improved water management practices and the conversion of gravity-fed irrigation to pressurised systems, but also the heavy reliance on other production inputs such as fertilizers, pesticides, and labour-saving, energy-intensive farm machinery. However, modern production practices rely heavily upon these inputs that has led to a dramatic increase in fossil fuel use, and raised many concerns over sustainable use of energy resources (Deike et al., 2008; Hülsbergen et al., 2001). Pimentel et al. (1973; 2003; 2002 a, b), Naylor, (1996) and Deike et al. (2008) have warned that dependency on fossil-fuels would be a potential threat to the growth and stability of world food production.

Issues of declining reliability of water supply as a result of climate change and climate variability, increasing costs of water availability such as high groundwater pumping costs due to high fuel prices, coupled with rising costs of modern farm inputs are influencing farmer's income (Pimentel et al., 2002b; Bhuyan, 2004). For example, delivering the 10 Ml of water needed by 1 hectare of irrigated corn from surface water sources requires the expenditure of about 880 kWh of fossil fuel (Batty and Keller, 1980). In contrast, when groundwater is pumped from a depth of 100 m to irrigate the same 1 ha corn crop, the energy cost increases to 28,500 kWh or more than 32 times the cost of surface water (Gleick et al., 2002). Singh et al. (2002) found that in an arid zone farming systems in India,, irrigation always consumed the majority of on-farm energy. They suggested that the energy-intensive demands of various crops should be factored into management decisions when determining the most appropriate crops for a given production system.

With declining fossil fuel reserves, increasing farm costs, and the changing reliability of water supply, it is important that long term planning for irrigated rice recognises that current and future production practices will be challenged. Efficient uses of water and energy resources are vital for increased yield from rice production, enhanced competitiveness as well as environmental sustainability. The need to increase water-dependent rice production and reduce dependency on energy resources, demands a better understanding of water and energy use patterns in high-input farming systems (Ozkan et al., 2004).

This paper contributes to food and energy policies by comparing energy, water and economic efficiencies of rice production in selected developing and developed countries where rice production is a significant farming enterprise.

2. Energy and Rice Production

Energy is an essential component of any agricultural system, whether the source is human, animal or mechanical. All phases of rice production require energy: when ploughing, applying fertilizers and pesticides, planting, watering, crop cultivation, harvesting, food processing, and transport (Chauhan et al., 2005; Mandal et al., 2002). Energy consumption in agriculture is directly related to the development of technology and the level of production from a system (Hatirli et al., 2006; Ozkan et al., 2004). Ancient subsistence rice cultivation practices involved low energy inputs through scattering of seed resulting in meagre yields. In contrast, modern, market-driven rice production practices, require precision techniques involving high energy inputs such as large quantities of fossil fuels to achieve substantially improved yields (Stout, 1990). In developed countries, where higher levels of mechanisation exist, the dependence on fossil fuels is even greater. However, spiralling fuel prices has necessitated a more careful and sustainable approach to energy management in modern rice cultivation practices.

Energy requirements in rice production are divided into two groups: direct and indirect (Schnepf, 2004; Pimental et al., 2002a,b). Direct energy is required to perform various tasks in crop production processes such as land preparation, irrigation, threshing, harvesting and transportation of farm produce. Indirect energy, on the other hand, is used in the manufacture, packaging and transport of fertilizers, pesticides and farm machinery (Pimental, 1992; Pimental et al., 2002b).

Energy inputs can be classified as commercial and non-commercial. Commercial energy is produced externally from the farm and includes electricity, diesel, fertilizer and other agro-chemicals, machinery and high yielding seed varieties. Non-commercial energy is self-generated and includes human labour, animals, farm-yard manure (FYM) and home-grown seeds (Stout, 1990).

3. Methodology

Energy Use Efficiency

Each agricultural input and output has its own energy values. For this study, we consider all farm inputs including machinery, seeds, agrochemicals (fertilisers, insecticides, herbicides, fungicides and molluscidies), fuels, farm yard manure, and human and animal labours. Similarly, we consider energy outputs from rice and straw. We collected the data in terms of physical units, which were then converted into energy units for the analysis using standard energy coefficients. Analysis of energy coefficients are based on energy equivalents available in the literature (Thakur and Makan, 1997; Mandal et al., 2002; Canakci et al., 2005; Hatirli et al., 2006) and their equivalents are presented in Table 1. The energy values used in this paper are the dietary energy value of agricultural output relative to the fossil energy expended to obtain it (Bonny, 1993). Finally, energy from all agricultural inputs and outputs was summed to obtain the total energy input and output.

The energy use efficiencies for rice cultivation were estimated then by the following ratios:

$$Energy\,ratio = \frac{Total\ energy\ output\ (kWh)}{Total\ energy\ input\ (kWh)} \tag{1}$$

$$Specific\,energy = \frac{Total\ energy\ input\ (kWh)}{Output\,of\ grain\,yield\ (kg)} \tag{2}$$

$$Energy\ \ productivity = \frac{Grain\ yield\ (kg)}{Total\ energy\,input\ (kWh)} \tag{3}$$

where, total energy input is the sum of all individual energy inputs (in kWh) such as human energy, tractor energy, energy through fertilizer, chemicals, seed, farm yards manure and irrigation. Similarly, the total energy output includes the energy obtained from grain production and by-products such as straw.

Economic Efficiency

Economic efficiency occurs when scarce resources are allocated and used such that net returns (gross returns minus costs) are maximised (Barker et al., 2003). The net return of rice production is calculated as gross returns minus the cost of all variable inputs, which includes the cost of irrigation, seed, fertilizer, chemical, and labour. Water productivity ($/m^3) measured in 'economic' terms, is the gross return divided by the amount of the irrigation water supplied to rice.

The economic efficiency of rice production was estimated as follows:

$$Water\ productivity(Economics) = \frac{Gross\ returns(\$)}{Volume\ of\ applied\ irrigation\ water\ (m^3)} \quad (4)$$

$$Benefit\ \ Cost\ Ratio\ (BCR) = \frac{Gross\ returns\ (\$)}{Total\ costs\ (\$)} \quad (5)$$

where, the BCR is the sum of the benefits ($) divided by the sum of the costs ($). If the ratio is greater than one, then the project is viable.

Water Use Efficiency

Water productivity (WP) is one of the key indicators of water use efficiency (Molden, 1997; Molden and Sakthivadivel, 1999). In this study, we define WP as the ratio of yield (kg) to the volume of applied irrigation water supplied (m^3).

$$Water\ productivity\ (kg/m^3) = \frac{Grain\ yield\ (kg)}{Volume\ of\ applied\ irrigation\ water\ (m^3)} \quad (6)$$

3.1 Data collection

The study used a vast dataset obtained for the 2001-2005 period from various projects in the International Rice Research Institute (IRRI), Philippines. Data for the USA was obtained from the University of Arkansas (2006) and AgCenter Research and Extension, Louisiana State University (2003). Data used in this study contained specific information such as rice production information at the plot level including machine, fuel, seed, fertiliser, chemicals, water use, and labour use.

The selected countries–6 developing and 2 developed countries–are major rice producers and consumers. Data from the selected developing countries includes Liuyuankou Irrigation System in Yellow River Basin, North West China; Rechna Doab in Punjab, Pakistan; Upper Pampanga River Integrated Irrigation System in Central Luzon, Philippines; Semarang and Pati Districts in Central Java, Indonesia; Banke district in Terai, Nepal; Myitthar Township in Mandalay Division, Myanmar. The data from the selected developed countries includes Coleambally Irrigation Area (CIA) in NSW, Australia and Arkansas in USA (Appendix 1).

Among the 8 countries used in this study, China, on average over the past decade, has the highest land area dedicated to rice production, followed by Indonesia and Myanmar; with developing countries dominating the total proportion of land area devoted to rice production (97.5%) (Table 2).

4. Results

Crop Productivity

Despite being the staple food for most Asian countries, rice yields remain low compared to other cereal crops. However, countries such as China and the Philippines have managed to achieve significant yield increases, due to substantial usage of fertilisers and high yielding varieties of rice. Figure 1 presents a brief comparison of rice yields from the selected developing and developed countries used in this study. The details of total input used in rice production are given in Table 3. Statistically, there is little difference in rice yield using either canal or tubewell irrigation. However, irrigated rice yield is almost 1.8 times higher than rainfed yield. Australia has the highest irrigated rice yield (9,500 kg/ha) while Pakistan has the lowest yield (2,491 kg/ha).

Energy Productivity

The energy-agriculture relationship is becoming increasingly important as the growing reliance on fossil fuels continues unabated with continued intensification of cropping systems such as in rice production. Tradeoffs exist between yield and energy inputs (Figure 2) as energy consumption is directly related to the development of technology and the level of production.

The total energy inputs and outputs for rice under various irrigation systems in a selection of developing and developed countries is shown in Figure 3, with the specific details of the energy inputs and outputs being presented in Table 4. Overall, indirect energy in the form of fertilisers and chemicals constitutes a major portion of total energy input. However, in the case of tubewell irrigation, direct energy was the major contributor to total energy inputs (Table 4). The average energy input use (7,112 kWh) in the selected developed countries is 1.2 times greater than the energy inputs (6,047 kWh) in the selected developing countries. This is due to high energy inputs such as chemical fertiliser, pesticides and insecticides. Similarly, the energy outputs and thus energy productivity in the selected developed countries are 1.82 times higher than the developing countries indicating that energy productivity, relative to all energy inputs, is higher in the selected developed countries than the selected developing countries.

Irrigation (both canal and tubewell) requires significant expenditure of fossil energy both for pumping and for delivering water to crops. On average, the amount of energy consumed in irrigated rice production (6,993 KWh) is two times higher than rainfed rice (3,531 kWh), while tubewell irrigation used 25% more energy than canal irrigation. Hodges et al. (1994) estimated that 15% of the annual total energy expended for all crop production is used to pump irrigation water. The large quantities of energy required to pump irrigation water are significant considerations both from the standpoint of energy and water resource management.

The energy efficiency indicators – energy ratio, specific energy, and energy productivity – varied with rice irrigation system (Figure 4), and selected developed and developing countries (Figure 5). The average of energy ratio (9.5) and energy productivity (1.17) of rainfed rice is significantly higher than the average energy ratio (5.7) and energy productivity (0.6) of tubewell (Figure 5). This is mainly due to higher energy inputs used in pumping. However, there was not much difference in average energy ratio and energy productivity between rainfed and canal irrigation (Figure 5). Furthermore, the tubewell irrigation of rice shows high average specific energy (1.8) as compared with canal irrigation (1.2) and rainfed rice (1.0).

The comparison between the selected developed and developing countries indicates higher energy ratios and higher energy productivity in developed countries (Figure 5). This reflects changes in technology and farm management that economised on energy, the adoption of conservation tillage; a switch to larger, multifunctional machines; the transition to more efficient methods of irrigation and less energy-intensive methods of fertilizer production. However, the specific energy for rice production using tubewell and canal irrigation was higher in developing countries than the selected developed countries (Figure 5).

Despite these efficiency gains, energy use in the selected developed countries is still high. This is because increased farm mechanisation in developed countries requires significant energy usage at particular stages of the rice production cycle to achieve optimum yields.

Economic Efficiency in Rice Production

Economic efficiency not only guides investment about what crops to grow but also the decisions about the quantity of input needed. The net return per ha and benefit costs analysis (BCA) of rice production are shown in Figure 6 and 7 with details of the input and output costs given in Table 5. Net return varied significantly between countries. Overall, rice production shows positive net returns for all selected countries (Table 5 and Figure 6). Similarly, the BCA of all the selected countries was greater than one, indicating rice profitability: Australia has the highest net returns ($1,397/ha) while Myanmar has the lowest ($89/ha).

Rice grown using canal irrigation ($490/ha) shows 11% higher net returns when compared with tubewell ($442/ha), and 182% higher returns when compared with rainfed rice ($174/ha). Similarly, the selected developed countries, on average, realised over 200% higher economic returns ($1029/ha) compared to the selected developing countries ($317/ha).

The water productivity of rice when measured in economic terms did not show a significant difference between the countries, and between the given rice irrigation system (Figure 8). However, Australia has the highest water productivity economics (0.2 kg/m^3), despite the relatively high water usage in a climate of highly variable water regimes, resulted in higher yields, while the lowest water productivity economics (0.1 kg/m^3) was found in Nepal (Figure 8).

Water productivity

Water productivity of rice between the selected countries is shown in Figure 9. China has the highest water productivity both for canal (1.21 kg/m^3) and tubewell (1.32 kg/m^3) irrigation. This is because of the adoption of water-saving irrigation practices, in particular alternate wetting and drying (AWD) (Bouman et al., 2007; Cabangon et al., 2004). The basic feature of the AWD method is to irrigate so that the soil alternates between periods of standing water and damp or dry soil conditions from 30 days after crop establishment up to harvesting (Moya et al., 2004). In general, rice grown on tubewell has higher water productivity (0.95 kg/m^3) than canal irrigation (0.84 kg/m^3), due to more timely and flexible water supply, which not only helped in reducing the irrigation water quantity but also increased yield (Figure 9).

The high water productivity of rice in China, attributed to different water-saving irrigation practices, especially AWD irrigation practices, highlight the important opportunities available for both developed and developing countries to increase water productivity whilst reducing water and energy inputs. Studies have shown (Mushtaq et al., 2006; Moya et al., 2004; Li and Barker, 2004; Belder et al.,

2004) that AWD irrigation practices save 5-30% of water without adversely affecting yields. The water saving would result in decreased pumping costs, reduced energy inputs and ultimately an increase in profits.

5. Discussion

Global rice production has more than doubled during the past 50 years. However, gains in yield have come at a considerable cost in terms of increased input use and energy consumption, as well as the depreciation of natural resource stocks. Rice is generally grown using the transplanting of seedlings under puddled field conditions. It requires huge amounts of input energy for the growing of seedlings, transplanting, puddling, and irrigation. Advances in agricultural technologies have seen rice yield and the use of energy resources markedly increase. Thus, the energy-yield relationship is becoming more and more important with enhanced mechanisation and agricultural intensification: considered to be the only means of raising agricultural output in land-limited situations.

Results show tradeoffs between yield and energy input uses with higher yields attributed to higher levels of input energy. Inputs such as fuel, electricity, machinery, seed, fertilizer and chemical take a significant share of the energy supplies needed in modern agricultural production systems, especially in rice production. The selected developed countries used in this study have higher energy productivity relative to all energy inputs compared to the selected developing counties, due to improvements in farm technology and farm management. China has the highest water productivity because of water-saving irrigation practices. Water saving irrigation practices offer opportunities for developed and developing countries to increase water productivity while at the same time capturing the economic and energy benefits of reduced pumping.

While greater water productivity will almost certainly be necessary to reduce the negative impacts of future water scarcity, it is important to keep in mind the distinction between energy and water productivity tradeoffs. Increasing water productivity in some instances does not necessarily result in increased benefits to society. For example, interventions may raise water productivity only at the expense of using other scarce resources and increasing greenhouse gases such as fossil fuels, with the net effect being a reduction in economic efficiency.

In the future policy planning, energy dependency will not only influence the overall economics of rice crop but also the selection of suitable irrigated crop varieties. Development of efficient water management practices such as alternate wetting and drying irrigation practices and its large scale implementation across the selected countries would result in increased rice productivity, reduced energy dependency, enhanced natural resource sustainability and ensuring future food security.

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Appendix 1: Characteristics of the Study Locations

- *China*: Data collected from a total of 45 farmers, out of which 12 were using tubewell irrigation, during 2002 in the Liuyuankou Irrigation System (LIS), located in the Yellow River Basin, North West China. Surface water from the Yellow River and local groundwater are two key sources of irrigation water in the irrigation systems in LIS. The LIS lies in a semi-arid climatic zone with a highly variable annual rainfall of 530 mm. The annual average temperature is 14ºC and annual evapotranspiration is 1,150 mm.

- *Australia*: Data collected from 18 farmers using canal irrigation during 2005/06 in the Coleambally Irrigation Area (CIA), New South Wales, Australia, which is located south of the Murrumbidgee River. The CIA was developed during the 1960's to make use of water diverted westward as a result of the Snowy Mountains Hydro-Electric Scheme. Water is diverted to the CIA from the Murrumbidgee River at Gogelderie Weir. The CIA lies in a semi-arid climatic zone with a highly variable annual rainfall of 530 mm. The annual average temperature is 20ºC and annual evapotranspiration is 1,000 mm.

- *Pakistan*: Data collected from a total of 188 farmers during 2001/02, out of which 53 farmers using tubewell for irrigation, were located in Sheikhupura, Mangtanwala and Dhaular sub-divisions in Rechna Doab (RD), Pakistan. RD utilise surface and groundwater for irrigation, with groundwater being the dominant source. The RD area lies in a semi-arid climatic zone with a highly variable annual rainfall of 530 mm. The annual average temperature is 21°C and annual evapotranspiration is 1,200 mm.

- *Philippines*: Data collected from a total of 150 farmers during the 2002 dry season, out of which 50 farmers were using tubewell for rice irrigation, in the Upper Pampanga River Integrated Irrigation System (UPRIIS), Central Luzon, Philippines. The UPRIIS covers an area of 102,000 ha and produces an average of 63 million tonnes of rice per annum. The climate in the UPRIIS is characterized by two pronounced seasons: dry from November to April with an average rainfall of 193 mm; wet from May to October with an average rainfall of 1654 mm. The average temperature ranges from 24°C to 3°C and evaporation varies from 665 mm to 503 mm depending on the time of year.
- *Indonesia*: Data was collected from 85 farmers Semarang and Pati Districts in Central Java, Indonesia during 2002/04 for both wet and dry seasons. Semarang and Pati has a tropical climate with two seasons: the wet season is from November to April influenced by the monsoon; while the dry season is from May to October influenced by the eastern monsoon. Annual rainfall is between 2,065–2,460 mm with maximum rainfall occuring in the months of December and January. The average temperature ranges from 28.0°C to 34.3°C.
- *Nepal*: Data was collected from 160 farmers during 2002/03 from the Banke district in Terai, Nepal. The total area of the Banke district is about 278,674 ha, in which rice is the dominant crop in summer. Heavy monsoon rains begin in June and end in September; this monsoon comprised about 87% of the year's total precipitation. The average annual rainfall of Banke District was 1,445 mm. Minimum mean monthly temperature was 19.0°C and the maximum mean monthly temperature was 31.2°.

- *Myanmar*: Data collected from 105 rice farmers during 2002/03, revealed that 30 farmers grew rainfed rice, from the Kingda Dam irrigated area in Mandalay Division, in particular Myitthar Township, Myanmar. Myitthar occupies 87,725 acres or 44.9% of the total Kingda Dam irrigated area. The average rainfall is 993 mm. Minimum mean monthly temperature is 21^{o}C and the maximum mean monthly temperature is 34^{o}C. Rice is the major crop grown during the wet season in Myitthar Township.

- *USA*: Data on the Northeast Louisiana Rice Area was made available from the University of Arkansas and Louisiana State University. The Northeast Louisiana Rice Area is characterized by flat to slightly rolling topography. Northeast Louisiana has a mixed-humid climate with more then 550 mm of precipitation. The average monthly temperature drops below 7^{o}C in winter.

Figure(s)

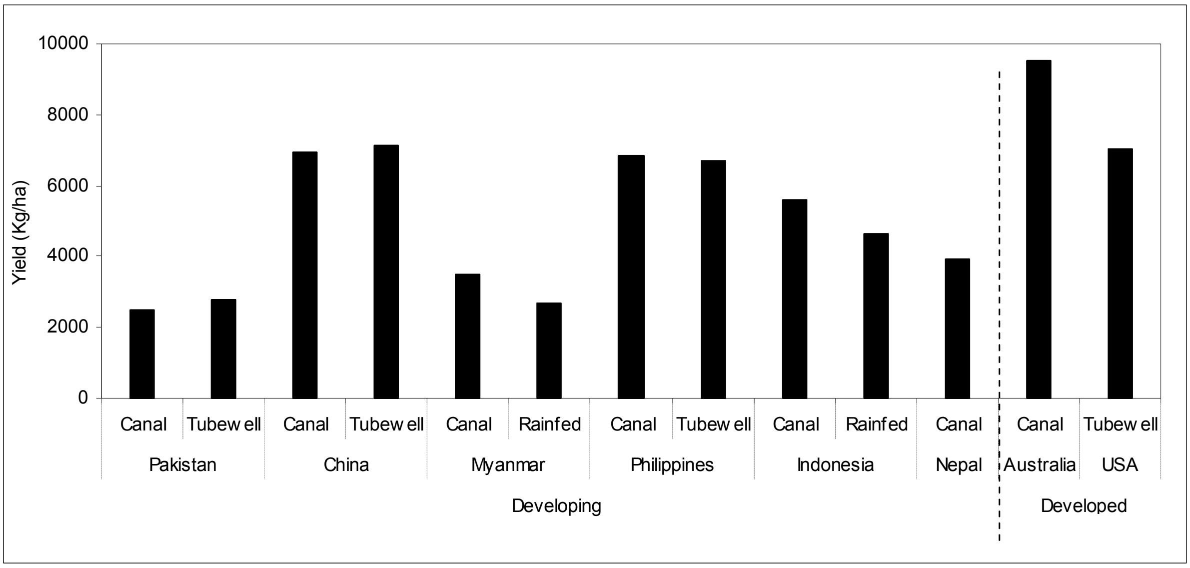

Figure 1 Comparison of rice yields in selected developing and developed countries using canal, tubewell and rainfed production systems.

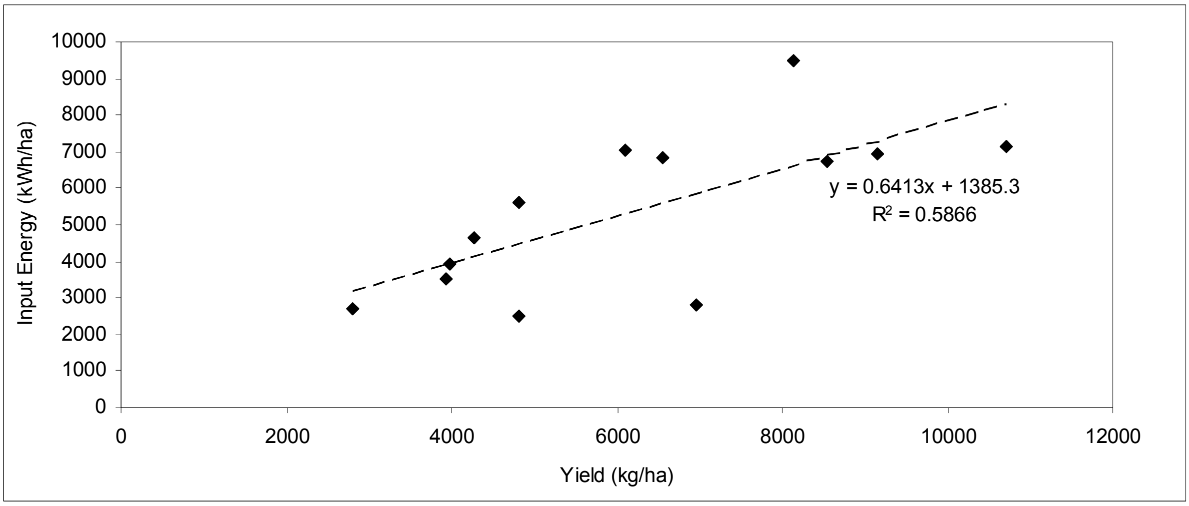

Figure 2 Tradeoffs between rice yield and energy inputs for the selected developing and developed countries.

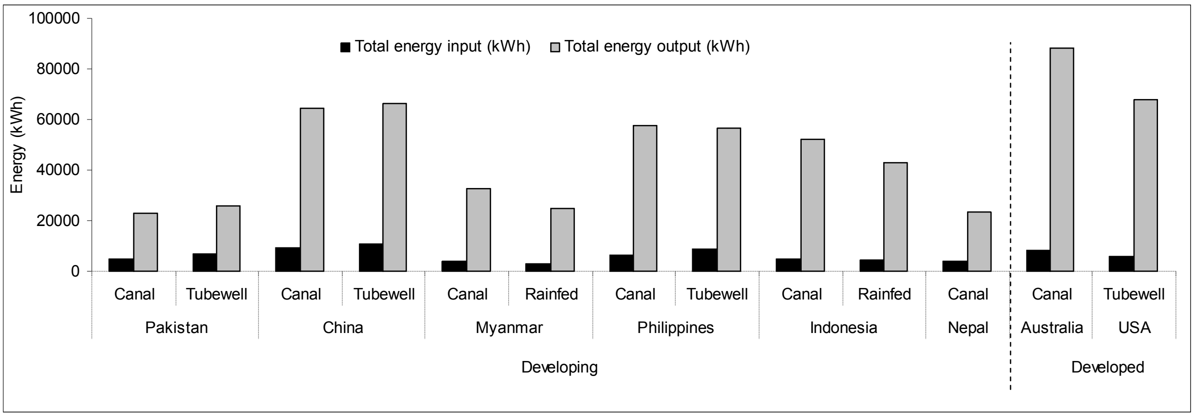

Figure 3 Total energy input and output of rice under different irrigation system for the selected developing and developed countries.

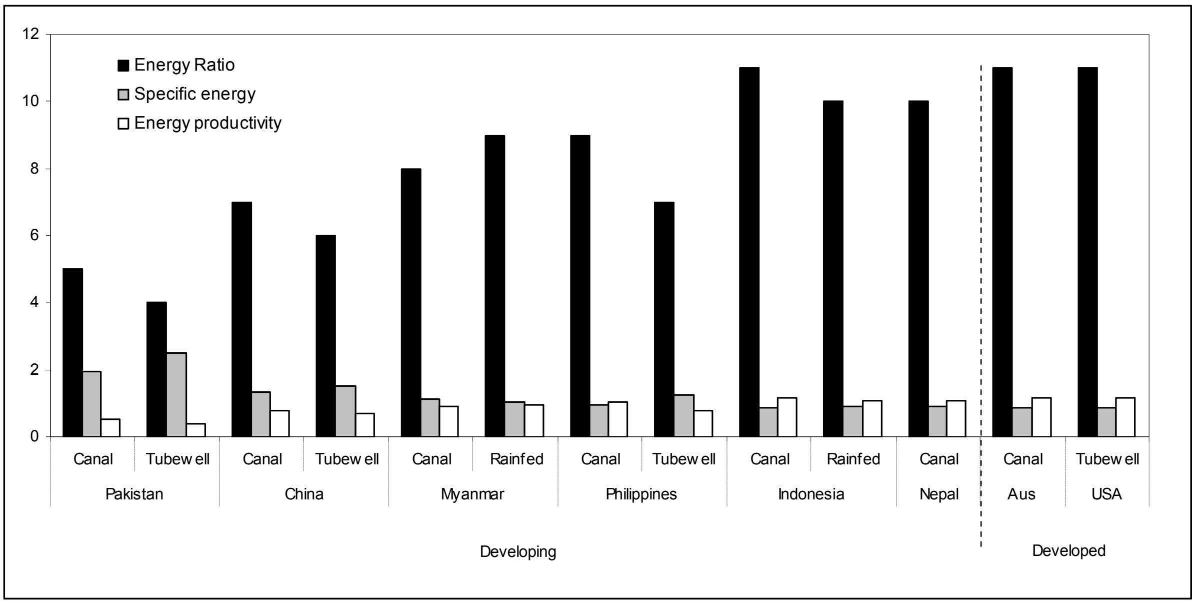

Figure 4 Energy ratio, specific energy, and energy productivity of rice production in canal, tubewell and rainfed irrigation systems for the selected developing and developed countries.

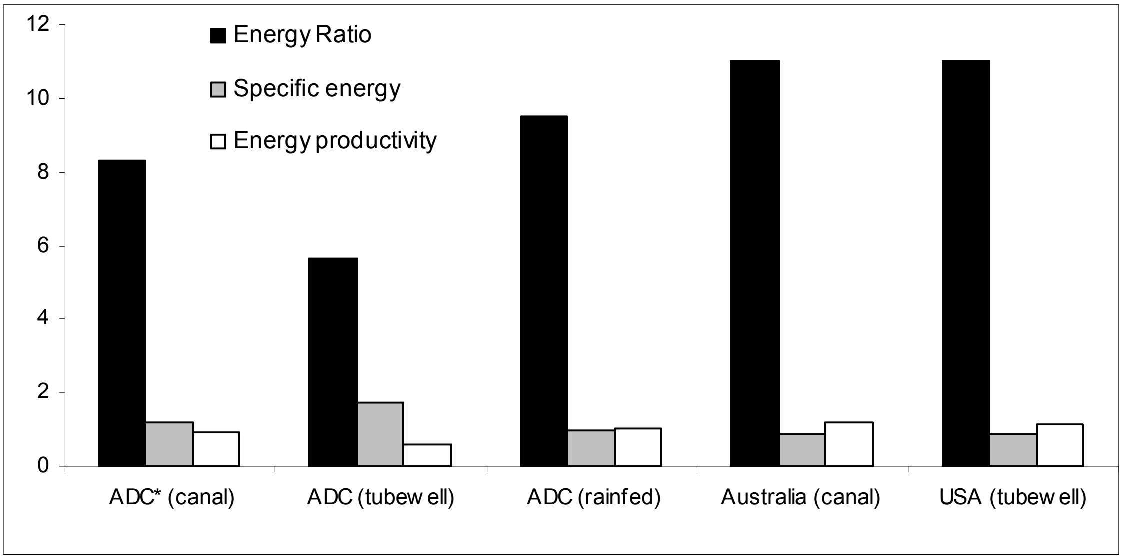

Figure 5 Average energy ratio, specific energy and energy productivity for the selected developing countries and developed countries. * ADC = average of developing countries

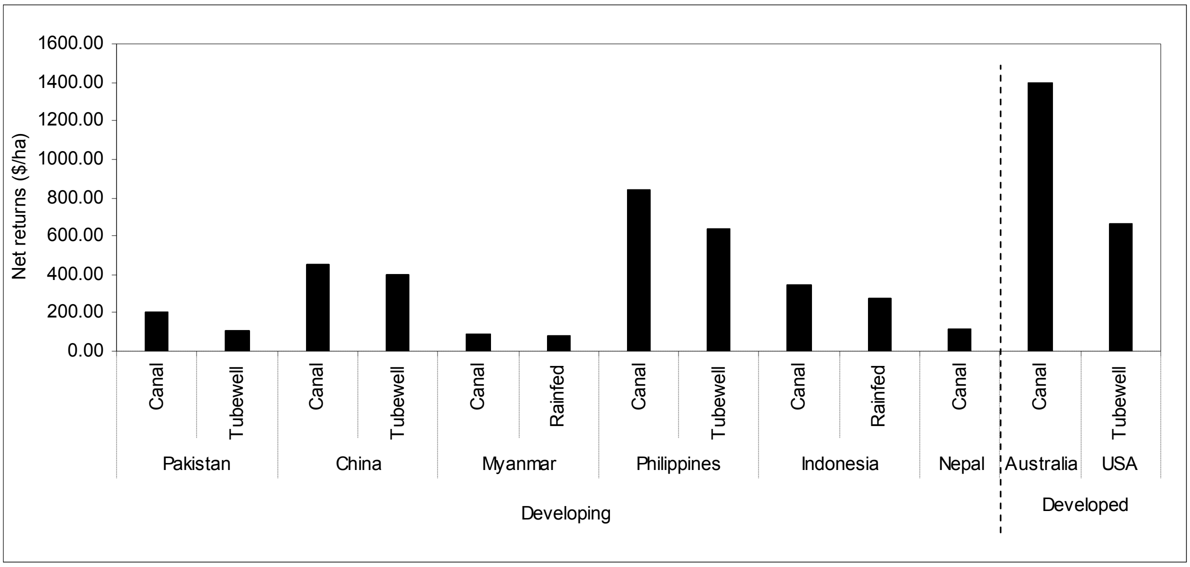

Figure 6 Net return of rice production from different irrigation systems for the selected developed and developing countries

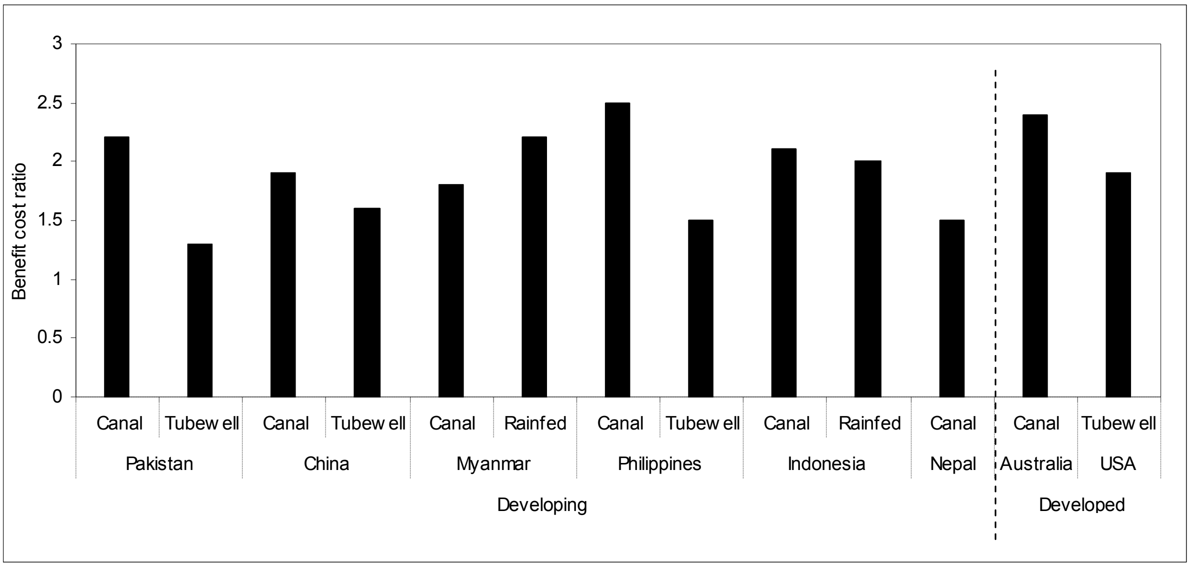

Figure 7 Benefit cost ratio of rice production from different irrigation systems for the selected developed and developing countries.

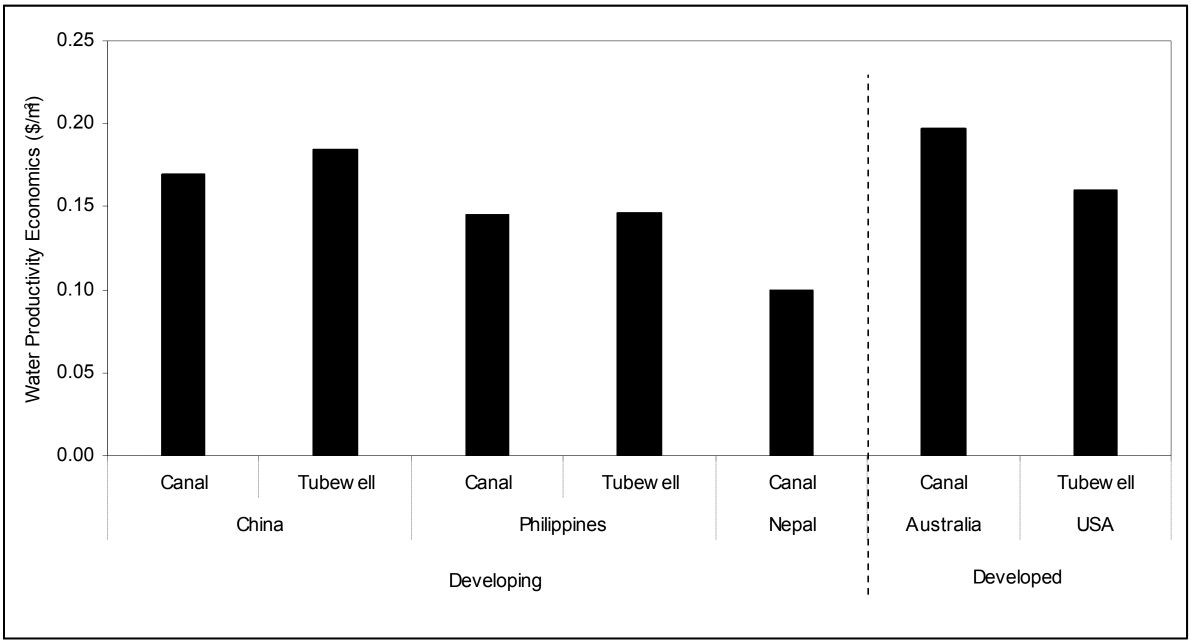

Figure 8 Water productivity measured in economic terms for the selected developing and developed countries.

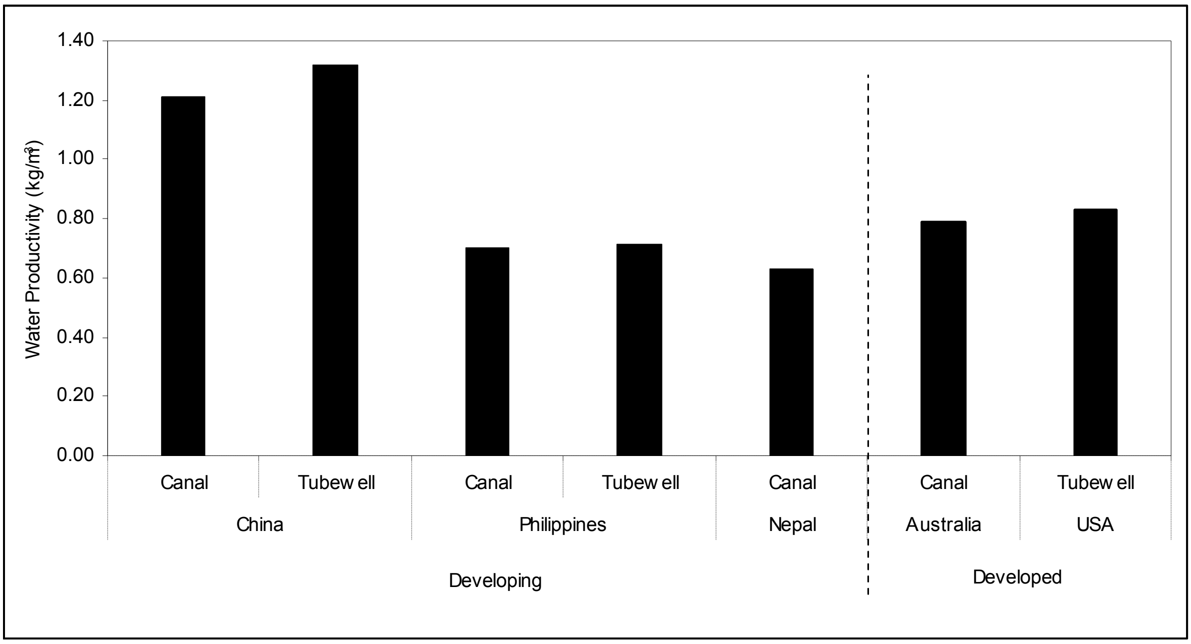

Figure 9 Water productivity of rice for the selected developed and developing countries

Table(s)

Table 1 Energy equivalence of inputs and outputs in rice production.

Operation	Unit	Energy equivalent (KWh)	References
Machinery (Tractor for land preparation)	hr	17.42	Mandal et al. (2002); Yilmaz et al. (2004)
Diesel	l	15.67	Mandal et al. (2002); Yilmaz et al. (2004); Hatirli et al. (2006)
Seed	kg	4.08	Mandal et al. (2002); Selim et al. (2006)
Fertilizer			
N	kg	16.83	Mandal et al. (2002)
P	kg	3.08	Mandal et al. (2002)
K	kg	1.86	Mandal et al. (2002)
Chemicals			
Insecticides	l	55.5	FAO2000
Herbicides	l	66.7	FAO2000
Molluscicides	l	28.1	Hetirli et al. (2006)
Fungicides	l	17.2	FAO2000
Farm yard manure	kg	0.07	Mandal et al. (2002)
Labour	day	4.32	Mandal et al. (2002); Yilmaz et al. (2005)
Animal labour	hr	1.4	Ozkan et al. (2004)
Yield	kg	4.08	Mandal et al. (2002); Selim et al. (2006)
Straw	kg	3.47	Mandal et al. (2002)

Table 2. Rice/paddy harvested area and percentage of rice to the total cereal area for the selected developing and developed countries.

Countries	Average Area (1997-2006) (000' ha)	Average Percentage (1997-2006) of rice area to the total cereal area
Australia	110	1
USA	1,293	2
China	29,718	35
Indonesia	11,625	77
Myanmar	6,377	91
Nepal	1,539	46
Pakistan	2,415	19
Philippines	3,953	61

Source: FAO (2007)

Table 3 Physical total inputs and outputs for rice production under different irrigation system per hectare for the selected developing and developed countries.

Operation	Unit	Pakistan		China		Philippines		Australia	Indonesia		Nepal	USA	Myanmar	
		Canal	Tubewell	Canal	Tubewell	Canal	Tubewell	Canal	Canal	Rainfed	Canal	Tubewell	Canal	Rainfed
Land prep (Tractor)	hr	5	5	7	8	8	8	2	5	4	3	5	5	4
Diesel	l	115	219	161	244	184	298	46	115	92	69	230	115	92
Seed	kg	45	48	102	105	160	182	150	28	33	56	64	50	50
Fertilizer														
N	kg	125	150	258	280	147	152	350	99	104	82	85	63	38
P	kg	40	41	105	110	20	23	125	89	63	50	23	38	13
K	kg	10	9	35	32	15	16	0	0	0	18	23	13	5
Chemicals														
Insecticides	l	0	0	1	2	0	0	0	2	1	0	0	1	0
	kg	0	0	0	0	0	0	0	0	0	0	4	0	0
Herbicides	l	2	2	2	3	1	1	6	0	0	0	5	2	0
	kg	0	0	0	0	0	0	0	0	0	0	0	0	0
Molluscides	l	0	0	0	0	0	0	0	0	0		5	0	0
	kg	0	0	0	0	0	0	0	0	0	0	0	0	0
Fungicides	l	0	0	1	2	0	0	0	0	0	0	4	0	0
	kg	0	0	0	0	0	0	0	0		0	0	0	0
Farm yard manure	kg	1300	1500	4500	500				408	0	835		1000	500
Irrigation	m^3	NA	NA	5717	5417	9600	9530	12000	NA	NA	6200	8500	NA	NA
Labour	day	70	78	187	205	59	66	16	169	152	155	17	96	69
Animal labour	hr	0	0	0	0	0	0	0	3	3	220	0	24	48
Yield	Kg	2491	2785	6925	7142	6846	6711	9500	5596	4625	3930	7036	3500	2700
Straw	Kg	3737	4178	10388	10712	8558	8389	14250	8394	6938	2080	11258	5250	4050
Water productivity	Kg/m^3	NA	NA	1.21	1.32	0.71	0.70	0.79	NA	NA	0.63	0.83	NA	NA

NA = not available

Table 4 Total energy input (kWh) and output (kWh) for rice production under different irrigation system per hectare for the selected developing and developed countries.

Operation	Pakistan		China		Philippines		Australia	Indonesia		Nepal	USA	Myanmar	
	Canal	Tubewell	Canal	Tubewell	Canal	Tubewell	Canal	Canal	Rainfed	Canal	Tubewell	Canal	Rainfed
Land preparation (Tractor)	87	87	122	139	139	139	40	88	70	57	78	85	66
Diesel	1807	3436	2529	3830	2883	4670	722	1807	1445	1084	3604	1807	1445
Seed	184	196	416	428	652	741	612	116	133	230	259	204	204
Fertilizer	0	0	0	0	0	0	0	0	0	0	0	0	0
N	2104	2525	4342	4712	2474	2558	5891	1664	1742	1385	1431	1052	631
P	123	127	323	339	62	71	385	274	193	154	71	116	39
K	19	17	65	60	28	29	0	0	0	34	43	23	9
Chemicals													
Insecticides	0	0	67	83	16	11	11	100	28	0	3	28	0
	0	0	0	0	0	0	0	0	0	0	0	0	0
Herbicides	100	120	140	167	40	40	400	0	0	0	334	100	0
	0	0	0	0	0	0	0	0	0	0	0	0	0
Molluscicides	0	0	0	0	3	3	0	0	0	0	126	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0
Fungicides	0	0	22	31	0	0	0	0	0	0	72	0	0
Farm yard manure	91	105	315	35	0	0	0	29	0	58	0	70	35
Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0
Labour	302	337	807	886	257	284	69	730	654	670	71	415	298
Animal labour	0	0	0	0	0	0	0	4	4	308	0	34	67
Total energy inputs	4816	6950	9149	10710	6555	8547	8130	4812	4268	3980	6093	3933	2794
Yield	10163	11363	28254	29138	27932	27381	38760	22832	18870	16034	28707	14280	11016
Straw	12966	14496	36045	37172	29695	29109	49448	29127	24073	7218	39064	18218	14054
Total energy output	23129	25859	64299	66310	57626	56490	88208	51959	42943	23252	67771	32498	25070
Energy Ratio	5	4	7	6	9	7	11	11	10	6	11	8	9
Specific energy	1.93	2.50	1.32	1.50	0.96	1.27	0.86	0.86	0.92	1.01	0.87	1.12	1.03
Energy productivity	0.52	0.40	0.76	0.67	1.04	0.79	1.17	1.16	1.08	0.99	1.15	0.89	0.97

Table 5 Net returns, benefit cost analysis and water productivity economic per hectare for the selected developing and developed countries.

Operation	Pakistan		China		Philippines		Australia	Indonesia		Nepal	USA	Myanmar	
	Canal	Tubewell	Canal	Tubewell	Canal	Tubewell	Canal	Canal	Rainfed	Irrigated	Unspecified	Tubewell	Rainfed
Land preparation + transplanting ($)	35.35	40.53	36.60	37.92	55.76	59.38	23.51	12.50	0.00	3.66	20.00	15.60	16.80
Seed ($)	2.77	2.78	22.80	22.80	48.88	54.92	30.00	8.99	11.94	7.65	28.70	14.00	12.00
Fertilizer ($)	27.17	39.53	78.86	78.86	69.00	76.86	188.54	55.33	50.14	23.20	128.00	15.40	8.56
Farm yard manure ($)	17.85	25.82	5.00	5.20	0.00	0.00	0.00	18.49	0.00	4.58	0.00	4.00	2.00
Chemicals ($)	15.92	16.08	22.50	24.66	31.03	35.46	173.00	9.73	3.33	0.00	51.73	13.00	0.00
Irrigation ($)	4.85	132.25	27.60	79.15	23.13	182.58	337.40	0.00	0.00	42.04	255.46	28.00	8.00
Harvesting ($)	26.68	28.09	58.90	60.25	0.00	0.00	213.64	0.00	0.00	0.00	0.00	12.00	10.40
Threshing ($)	17.79	18.73	40.20	42.30	0.00	0.00	0.00	0.00	0.00	1.72	0.00	5.20	5.20
Land rent ($)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Labour ($)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hired labour ($)	23.03	29.77	228.80	245.55	240.24	278.03	0.00	161.02	167.67	113.91	167.50	46.00	44.40
Family labour ($)	0.00	0.00	0.00	0.00	86.51	74.04	0.00	43.17	36.44	0.00	52.18	34.40	14.40
Animal labour ($)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.07	0.00	22.27	0.00	6.00	16.80
Total labour use ($)	23.03	29.77	0.00	0.00	326.75	352.09	0.00	0.00	0.00	136.18	219.68	0.00	0.00
Total paid-out costs ($)	171.40	333.58	521.26	596.69	468.04	687.23	966.08	266.07	233.08	219.03	703.57	107.20	62.96
Total cost ($)	171.40	333.58	521.26	596.69	554.55	761.27	966.08	309.23	269.53	219.03	703.57	107.20	62.96
Miscellaneous costs ($)	0.00	0.00	0.00	0.00	12.54	17.11	105.00	0.00	0.00	0.00	0.00	0.00	0.00
Gross return ($)	374.20	437.87	967.68	997.00	1392.49	1394.23	2363.64	652.87	539.58	331.66	1365.00	196.00	140.00
Net return ($)	202.8	104.3	446.4	371.0	837.9	633.0	1397.55	343.63	270.06	112.64	661.43	88.80	77.04
Benefit cost ratio	2.18	1.31	1.86	1.67	2.51	1.83	2.45	2.11	2.00	1.51	1.94	1.83	2.22
Water productivity Economics ($/m^3)	NA	NA	0.17	0.18	0.15	0.15	0.20	NA	NA	0.1	0.16	NA	NA